Muon-Induced Spallation in the Sudbury Neutrino Observatory

A. D. Marino, Y. D. Chan, X. Chen, K. T. Lesko, C. E. Okada, and A. W. P. Poon

In the Sudbury Neutrino Observatory (SNO) high-energy atmospheric muons can break apart the ^{16}O and ^{2}H nuclei in the 6 meter diameter heavy water sphere at the center of the detector, producing free neutrons and other nuclei, some of which can be radioactive. Thus the study of muon-induced spallation products is important since they form a background to the neutral-current and charged-current solar neutrino signals.

The radioactive nuclei produced by the fragmentation of ^{16}O are problematic if they produce beta or gamma rays with an energy above the detector threshold of around 4 MeV. By studying the Table of Isotopes [1], one can see that, of the radioactive nuclei with A$\leq$16 which produce beta or gamma rays with energy greater than 3 MeV, the longest lived nuclei are $^{16}_{7}$N, $^{11}_{4}$Be, and $^{10}_{6}$C with half-lives of 7.13 s, 13.8 s, 19.255 s respectively.

In addition to the radioactive nuclei, free neutrons can be produced by the both by the spallation of ^{16}O nuclei and by the dissociation of deuterium nuclei. Neutrons produced in the heavy water will typically randomly walk around the detector for 1-2 m before capturing on deuterium nuclei and producing a 6.25 MeV gamma ray. If the neutron should reach the acrylic vessel or the light water region of the detector, it will instead capture very rapidly on the hydrogen nuclei producing a 2.2 MeV gamma, which is too low in energy to be detected. Monte Carlo simulations of the detector predict a lifetime of approximately 40 msec for neutrons produced uniformly inside the heavy water region of the detector.

A study of the events following muons was performed. The muons in the detector were identified by the fact that they deposit a lot of energy in the detector and thus have a larger number of phototube hits. They will also deposit energy in the water buffer surrounding the detector and were therefore also to have light present in the outward looking tubes. The muons were also subjected to cuts on the timing of the PMT hits to remove instrumental backgrounds and were required to reconstruct within 750 cm of the detector center. For the muon followers, events within 2 minutes after a muon were studied. Several cuts on the PMT timing and charge distributions to remove instrumental background were applied to the data and the events were required to reconstruct inside the detector. A control sample of events 5-7 minutes after the muon were also studied.

The observed lifetime of the muon followers in the detector was found to be 35 ± 1 msec, which is close to the expected lifetime of free neutrons produced in the heavy water region of the detector. When compared to the events in the control sample, the majority of the events after the muon reconstructed inside the heavy water while the events in the control sample tended to reconstruct in the light water region. In looking at the distribution of PMT hits for these events following muons, they have a very similar spectrum to the 6.13 MeV gamma rays produced by the ^{16}N source. Therefore it appears that the majority of these muon-induced events are free neutrons.

The observation of these neutron-like events following muons gives hope for a neutral-current solar neutrino measurement in the pure D_2O phase of the detector. Further studies will attempt to identify longer lived-decay products produced by the spallation of ^{16}O nuclei.

References

[1] Firestone, R. *et. al.*, *Table of Isotopes*, 8th Edition, John Wiley and Sons, (New York: 1996)